Blue Whale Behavioral Response Study & Field Testing of the New Bioacoustic Probe

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LONG-TERM GOALS

Task 1: Blue Whales Behavioral Response Study
The behavioral response of large whales to commercial shipping and other low-frequency anthropogenic sound is not well understood. The PCAD model (NRC 2005) for assessing sound impacts on marine mammals calls for studies on sound source characteristics and the behavioral impact of specific sources on individual animals. Our goal is to understand the vocal and behavioral response of individual blue whales to high-intensity ship noise, resulting from the close geographic association between known foraging grounds and commercial shipping lanes off California. To accomplish this goal we deploy acoustic recording tags on individual blue whales within and near the shipping lanes while concurrently monitoring shipping traffic using AIS. The behavioral reaction of the whale to ship is then evaluated based on the tag data, the overall noise level, how close the ship approached.

Task 2: Field testing the new Bioacoustic Probe:
Tagging studies of odontocetes have yielded incredible insights into the diving, movement, and daily activities patterns of several species. Missing from most of these studies has been information on the

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acoustic environment in which the animal is living and the sounds produced by the animals during different activities. Working with Greeneridge Sciences, we will use the new Acousonde to initiate studies of beaked whale and other large odontocete whale species in the Pacific. Although our aim is to address several scientific questions relating to diving behavior, vocal behavior, and swimming mechanics with the data collected during these deployments, the primary goal of this project is to conduct field tests of the Acousonde with several species of cetacean and to refine the operation of the tag for robust field operation in the future.

OBJECTIVES

Task 1: Blue whale behavioral response study:
Our specific objectives are the following:

(1) Do blue whales exposed to high-intensity ship noise change their calling or diving behavior?

(2) What is the form of the response (cessation of feeding, change in orientation, change in vocalization rate or intensity, change in swimming speed, etc.)

(3) Is there a threshold sound level that elicits a response by blue whales?

(4) How long does the behavioral reaction persist relative to the increased noise level?

(5) What are the potential energetic and social costs of any response to noise?

Task 2: Field testing the new Bioacoustic Probe
The target specifications of the Acousonde include maximum depth of 3000m, maximum sustained acoustic sample rate of 232kHz, storage of 8Gb, 2 channels of acoustic data, and 3-dimensional accelerometer and compass. Our primary goal is to evaluate the functionality of the tag when used with odontocetes and to begin collection of vocal and diving behavior on a wide variety of odontocete species.

APPROACH

Task 1: Blue whale behavioral response study:
We evaluate the behavioral response of blue whales to intense ship noise and close ship approach using suction-cup attached acoustic recording tags and GPS Fastlock location tags. The proximity of shipping routes into southern and central California ports with predictable blue whale feeding grounds makes this an ideal location of the study of the impact of intense low-frequency noise on whale behavior. We monitor the vocal and dive behavior of blue whales using the B-Probe (Greeneridge Sciences) and the fine-scale movements of whales using the MK10 (Wildlife Computers). The B-Probe also records temperature, depth, and 2-axis acceleration, enabling the derivation of instantaneous body orientation (i.e., tilt and roll), as described by Goldbogen *et al.* (2006). The MK10 records depth enabling the two tag records to be synched when deployed on the same animals or two animals in a pair.

Ship locations are monitored using a real-time AIS receiver installed aboard the tagging boat and from two shore stations near Santa Barbara. The shore stations provide the entirety of the ship approach into the Channel and on to the Port of Los Angeles or Long Beach. The boat-mounted AIS provides real-time information to the tagging team on the closest point of approach to the tagged whale and the

speed and track of the approaching vessel so that the team can move out of the shipping lanes before the ship is very close. Once tagged, the tagged whale's position and surface behavior are monitored and the whale is photographed for individual ID. All variables are evaluated within the context of the local ambient noise prior to close ship approach and are compared to whale behavior in the absence of high-intensity noise.

Acoustic data collected by the B-Probe is analyzed to determine the presence and spectral characteristics of sounds produced by the whales, the ambient noise level prior to ship approach, and the received sound level of the passing ship. We took two different approaches to determine received sound levels at an animal when a ship was close. The main reason for this is that there is a high level of flow noise as the attached tag moves through the water, masking our ability to directly measure noise from the ships when the flow noise is high. During most behaviors the animal is swimming, therefore flow noise is usually high and broadband (150 dB and 0-1000 Hz). However, there are "quiet times" during the dive sequence that could be used to determine the received level of the ship on the tag. One such time is right after a deep forging lunge when acceleration is at a minimum. These typically occur during the daytime deep foraging events. We are still investigating a night time period with low flow noise.

Because of the complications with flow noise on the tag, our first method to estimate received levels at the animal was to use ship noise measurements from our seafloor instrument in the Santa Barbara Channel combined with ship passage information. Estimated source level for a given ship was calculated by using the closest distance of the ship to the HARP. AIS data provided exact time of passage and associated latitude and longitude position of the ship; the distance to the HARP was calculated based on this position and the known position of the HARP. At the time of closest point of approach, the calibrated received level of the ship on the HARP was calculated in 1/3 third and 1-Octave bands from 20-1000Hz over a 5 second period. Loss due to propagation was assumed to be spherical spreading loss (20*log(distance from the HARP to Ship)) and added to the received levels to get estimated source level. To determine the received level at the animal when the ship passed, the closest distance of the ship to the animal was used to add in the appropriate transmission loss. One of the major assumptions with this method and likely a source of error are the unknown sound propagation characteristics both from the ship to the HARP and the ship to the animal.

Our approach to measuring the received sound level of passing ships has evolved this year to allow for better measurements of received level at the closest point of ship approach and to allow for comparison of the known noise spectra for specific ships. The new method takes advantage of the periods of low flow noise on the tag to estimate received levels. Specifically, we analyzed received levels on the tag when the whales were at a deep foraging lunge, where swimming speed (measured from flow noise) and acceleration were at a minimum (Fig.1) and no ship was present. Sound measurements were made over a 5 second period and analysed in 1 Hz bins and 1-octave band centered at 31.5Hz and the sensitivity of the hydrophone was accounted for. We then evaluated the noise spectra and estimate over all noise levels at the same point in the dive closest to the ship's approach. These ambient and ship spectra are then compared to evaluate received level at the animal, explicitly taking into account noise generated by the whale swimming through the water. We expect the received levels to be higher when a ship is close by. In some cases, the measured received level is not during the closest point of approach and we estimated received level at close approach using the distance of the ship to the animals and spherical spreading loss model, typical of the deep basins in the Santa Barbara Channel

This approach should also allow us to identify times of close ship approach when we are not there to observe it. Noise can be measured at the same point during each dive to control for flow noise, and outliers that may represent close approaches can be identified.

Dive depth and body orientation are measured by the sensors on the tag, and additional behavioral variables are derived from the auxiliary sensors, including acceleration, fluke rate, and feeding behavior, such as the presence of vertical or horizontal lunges. These behavioral measures are used to describe swimming mechanics, which may be used to derive energy expenditure (Goldbogen *et al.* 2006). Kinematic data for the tag deployments with a close approach of <1000m were summarized and presented as deviations around the mean (or anomaly). Behaviors analyzed included dive behavior (duration, number of lunges), surface behavior (durations, number of breaths), Although swimming speed is another important behavior to consider- because it is calculated from flow noise, when a ship is close “noise” increases, therefore confounding our measurement of swim speed.

Position data from the MK10 is used to evaluate fine-scale movements of the animals within and near the shipping lanes. Nighttime movements and behavior which cannot be effectively monitored by the research team are recorded on the MK10 for later evaluation of close ship approaches and behavioral changes during this period.

This project is co-managed by the lead investigators Erin Oleson of UCSD and NOAA and John Calambokidis of Cascadia Research. Erin and John have been studying the diving and vocal behavior of blue whales using suction-cup attached tags for 10 years. John has extensive knowledge of blue whale distribution and behavior and has maintained a photo-ID catalog of eastern North Pacific blue whales since the late 1970s. Megan McKenna, a PhD student at UCSD,has been developing methods for assessing noise levels during close ship approach, monitors trends in ship traffic from the AIS data, and is evaluating ship noise characteristics, including individual ship sound source characteristics based on continuous acoustic recordings using High-Frequency Acoustic Recording Packages (HARPs) deployed at several sites in and around the Santa Barbara Channel. Jeremy Goldbogen, a Postdoctoral Researcher at Scripps, has also joined our team to evaluate the kinematics of the whale response, including development of new methods to evaluate whale diving behavior through time to detect changes in behavior. The project is conducted in collaboration with Channel Islands National Marine Sanctuary and they are providing ship support on the R/V Shearwater.

Task 2: Filed testing the new Bioacoustic Probe:
Tagging efforts will occur off Southern California and in Hawaii in conjunction with ongoing survey and tagging efforts in those regions. Off Southern California, our efforts will be coordinated with visual and acoustic surveys underway as part of the SoCal BRS and other projects in the instrumented range.

WORK COMPLETED

Task1: Blue whale behavioral response study:
Deployments on blue whales in and around the Santa Barbara Channel shipping lanes have been conducted since 2008. Deployments during the current field season are listed in Table 1. A total of 5 blue whale deployments of BProbe acoustic tags and 12 deployments of Mk10 Fastloc GPS tags of over an hour each were completed.

These efforts targeted primarily animals in or near the shipping lanes and successfully documented at least three very close approaches (within 200m) of ships by instrumented animals. Additional approaches of ships at slightly greater distance (200 to 1,000 m) were also documented. There may be additional close approaches that occurred at night and while the whales were not monitored. New methods to identify close approaches by ships based on the BProbe acoustic data are being evaluated.

Tagging efforts in 2010 were complicated by a recent shift of commercial shipping traffic out of the shipping lanes in the Santa Barbara Channel due to new Air Quality regulations. On July 1, 2009 a new California Air Resources Board (CARB) rule went into effect that required commercial ships to burn low-sulfur fuel when traveling with in 24 nautical miles of the California's coastline (Law 2009). The goal of the rule was to improve air quality in California's coastal communities. Ship traffic both before and after the CARB rule in the SBC and south was monitored using the Automatic Identification System (AIS); the shore station was located at Coal Oil Point, just west of Santa Barbara (34º24'29.4N 119º50'31.2"W).

In response to this rule, commercial ships changed their traditional transit routes through the Santa Barbara Channel (SBC) from the designated traffic separation scheme (TSS) to a route south of the Northern Channel Islands (Fig.2). Analysis of the ship traffic data showed that the response was immediate and daily traffic in the channel declined by 64% by the end of July 2009. Prior to the July 1 CARB rule, commercial ship traffic in the SBC was already on the decline, in response to the global economic slow down.

The shift and decrease in traffic posed a significant challenge to our proposed research. Tagging efforts late in 2010 and in 2011 may shift to ship approaches off central California to ensure the collection of additional samples. Ships traveling south of the islands do not transit a specific route; instead the region of possible transit was unpredictable and spans 15+ km region. Working south of the islands increases travel time from ports, and because ship routs are not as predictable, determining the area to work where ships and whales overlap is difficult, at best.

Task 2: Field testing the new Bioacoustic Probe
Our Acousonde tag has recently been delivered and was deployed on a blue whale during the SoCal BRS (Table 1). The deployment was successful and collected over 15 hours of data. Details analysis of the data from that deployment is still underway. Additional deployments are planned for October 2010 during the next phase of blue whale tagging.

Table 1. Acoustic and location tag deployments on blue whale in and near the shipping lanes in 2010.

Deployment Time	TagType	Species	Location	OnLat	OnLong	OffTime	Deployment duration (hrs)
Deployments during Shearwater trip July 2010 in SB Channel, south of shipping lanes but no ships							
7/26/10 13:25	Mk10	Bm	Santa Barbara Channel			7/26/10 14:30	1.08
7/26/10 15:26	Mk10	Bm	Santa Barbara Channel			7/26/10 15:30	0.07
7/26/10 15:41	Mk10	Bm	Santa Barbara Channel			7/27/10 0:22	8.68
7/26/10 14:13	Mk10	Bm	Santa Barbara Channel			7/26/10 15:05	0.87
7/26/10 17:01	Mk10	Bm	Santa Barbara Channel			7/26/2010 20:27	3.43
7/27/10 12:37	Bprobe	Bm	Santa Barbara Channel	34 08.59	120 15.56	7/27/2010 14:15	1.63
7/27/10 14:30	Bprobe	Bm	Santa Barbara Channel	34 08.15	120 16.06	7/27/2010 20:23	5.88
7/27/10 14:30	Mk10	Bm	Santa Barbara Channel	34 08.15	120 16.06	7/27/2010 17:25	2.92
7/27/10 17:00	Mk10	Bm	Santa Barbara Channel	34 08.33	120 17.00	7/27/2010 18:35	1.58
7/27/10 17:35	Mk10	Bm	Santa Barbara Channel	34 08.58	120 17.07	7/28/2010 1:01	7.43
7/28/10 13:55	Bprobe	Mn	Santa Barbara Channel	34 10.33	120 16.44	7/28/2010 17:00	3.08
7/28/10 14:29	Bprobe	Mn	Santa Barbara Channel	34 10.46	120 16.47	7/28/2010 17:19	2.83
7/28/10 16:24	Mk10	Bm	Santa Barbara Channel	34 09.33	120 16.21	7/28/2010 20:16	3.87
Deployments during BRS that either involve night data, Mk10 movements near shipping lanes or Acousonde							

Deployment Time	**TagType**	**Species**	**Location**	**OnLat**	**OnLong**	**OffTime**	**Deployment duration (hrs)**
8/23/2010 14:10	Bprobe	Bm	Long Beach	33 34.89	118 04.37	8/23/2010 15:24	1.2
8/23/2010 14:39	Mk10	Bm	Long Beach	33 34.10	118 03.99	8/24/2010 7:10	16.5
8/23/2010 15:44	Bprobe	Bm	Long Beach	33 35.22	118 04.84	8/23/2010 17:17	1.5
8/23/2010 18:10	Mk10	Bm	Long Beach	33 36.20	118 04.92	8/23/2010 21:38	3.5
8/28/2010 8:15	D-tag	Bm	Long Beach	33 41.09	118 19.33	8/29/2010 18:37	34.4
8/28/2010 17:05	Mk10	Bm	Long Beach	33 38.98	118 17.60	8/28/2010 21:33	4.5
8/30/2010 16:02	Mk10	Pm	Santa Monica Bay	33 51.03	118 37.36	8/31/2010 4:20	12.3
8/31/2010 9:28	Bprobe	Bm	Santa Monica Bay	33 47.16	118 30.47	8/31/2010 20:06	10.6
9/2/2010 12:38	Mk10	Bm	Santa Monica Bay	33 49.78	118 34.54	9/3/2010 6:42	18.1
9/3/2010 12:48	Mk10	Bm	Santa Monica Bay	33 50.20	118 36.36	9/4/2010 5:57	17.2
9/8/2010 13:07	D-tag	Bm	SB Channel	34 00.14	119 09.67	9/8/2010 16:47	3.7
9/22/2010 10:47	Dtag	Bm	Palos Verdes	33 47.96	118 31.09	9/22/2010 16:24	5.6
9/22/2010 15:54	Acousonde	Bm	Palos Verdes	33 46.44	118 29.24	9/23/2010 7:00	15.1
9/23/2010 14:55	Dtag	Bm	Palos Verdes	33 42.94	11823.82	9/23/2010 17:16	2.4

RESULTS

Task 1: Blue whale behavioral response study
Change in ship routing and the acoustic enviroment
The change in ship traffic is positive for animals in the Santa Barbara channel- both decreasing the risk of ship strike, and a significant reduction in background noise levels. There is a lack of historical sightings data south of the islands, therefore is it difficult to evaluate the change in impact.

To evaluate the change in potential acoustic impact, acoustic data from two seafloor instruments in the region were analyzed to determine the change in average background noise levels at 40 Hz (a frequency band dominated by ship noise): one site in the SBC and another south of Santa Cruz Island (Fig.3a). Calibrated monthly sound pressure levels at 40 Hz were calculated by averaging 225s sections of acoustic data and correcting for the sensitivity of the hydrophone. Figure 3b shows the decline in average noise levels in the SBC. The decrease in levels from 2008 through July 2009 is from a reduction in ship traffic related to the economy. After July 2009, the drop in levels is a result in the change in commercial ship traffic route patterns. Overlaid on the Figure 3b is the average number of ships per day for each month from the AIS data. The results of a correlation test between sound levels and ship traffic showed a strong relationship between average sound levels and commercial ship traffic (coeff =0 .96 Pval=0.001). The site south of Santa Cruz Island showed a 5 dB increase after July 2009.

This decrease in ocean noise in the SBC related to the human activity improves the acoustic habitat quality for marine organisms that rely on sound for basic life functions. Blue whales rely on the ability to perceive, recognize and interpret sounds from conspecifics, predators, and/or natural background noise; the introduction of anthropogenic noise from ships to the marine environment reduces both the sender’s and the receiver’s performance, specifically the frequency range at which blue whale communicate (Clark et al 2009).

Evaluation Of Animals Movement at Night
Dramatic differences in diving behavior were seen during the 25 hour deployment from 15-16 August 2008 (Figure 4). Dives at night were much shorter and shallower than during the day and transitioned around the time of sunrise and sunset. These are consistent with past night-time behavior data from blue whales. The cumulative time spent in waters close enough to the surface to be more vulnerable to ship strikes were dramatically higher at night than in the day (Figure 5). During the day this whale spent only 33% of the time shallower than 15 m but at night 70% of the time was this depth or shallower. This would potentially make whales almost twice as likely to be in the depth range vulnerable to ship strikes at night as in the day.

Evaluation of noise levels during close approach and identification of close approaches
Our preliminary analysis of received sound levels at the whale during close approaches based on tag data has shown promise. A comparision of relative received levels at the initial deceleration of a deep foraging dive indicate that when.the ship was within about 200m of the animal, received levels were 15-20 dB higher than when a ship was not present (Fig. 6). However, when a ship was 3.5km from the deep foraging whale, the ship noise was not detected over the flow noise on the tag. This latter result is problematic in that deep foraging dives generally occur 15-20 mintutes apart- enough time for a ship to move 10km. The data will be further analysed to try to determine “quiet times” in flow noise to decrease the time between received level measurments.

Behavioral Response based on Kinematic variables
To date we have collected acoustic and high-resolution tracks from three whales that were very closely (<200m) approached by commercial ships within the shipping lanes. Analysis of these records suggests that the close approach does not elicit a strong reaction by the whales; however, the whale do appear to alter their surfacing behavior immediately following the close ship approach (Fig.7). We found a significant increase (> 1 standard deviation from the mean of all dives) in the surface time and number of breaths. High-resolution tracks of MK10 tagged aniamls indicate that whales are foraging within the shipping lanes and remain in the area for at least several hours.

Vocal Response related to the close approach of a ship
Of the whales tagged with the acoustic tag, only one was a calling animal, making it difficult to evaluate significant changes in vocal behavior. Figure 8 shows the presence of calls before, during and after a close approach of a ship. We are investigating other ways to evaluate calling behavior in the presence of a ship, including analysis of HARP data to find examples when there calling whales and ships in close proximity to the HARP. A blue whale B call detector was created and run on HARP deployments in October 2005, 2007, 2008 and 2009. The next step to this analysis will be combining the results with ship passage information from AIS and the acoustic data.

Task 2: Field testing the new Bioacoustic Probe
The Acousconde acoustic tag was deliverd in mid-September 2010 and was successfully deployed on blue whales off southern California during the SoCal BRS study. We will begin field tests on odonotocetes near Hawaii in October 2010.

IMPACT/APPLICATIONS

Task 1: Blue whale behavioral response study
We anticipate one additional year of field effort toward this project which should yield additional data with which we can evaluate blue whale response to loud ship noise. The results of our tagging and monitoring studies will provide the baseline data needed on sound source (commercial ships and sonars), the behavioral response of blue whales to this source, and an estimate of how these responses may relate to the life functions, such as feeding, migration, and social behavior, of this endangered species.

Task 2: Field testing the new Bioacoustic Probe:
The Acousonde acoustic recording tag includes improved acoustic and auxiliary sensors, providing the capability to collect acoustic data up to 125 kHz bandwidth and animal orientation in 3-dimensions, in addition to dive depth. The new tag should be capable of providing valuable acoustic and dive data from medium to large odontocete cetaceans, a technological and scientific improvement over the previous tag technology. Acoustic tag studies are needed on odontocetes as these species have displayed vulnerability to anthropogenic noise sources.

RELATED PROJECTS

Task 1: Blue whale behavioral response study:
Several agencies and insitituions are contributing to the greater goals of this project. Support has been provided by the Channel Islands National Marine Sanctuary and Steve Katz in particular, who provided time on their vessel R/V Shearwater in 2009 and 2010. Additional funding has been provided by NMFS Marine Mammal Conservation Division. They are particulary interested in the reaction of

the whales to the close ship approach, an inquiry that fits nicely with this work. Finally, High-Frequency Acoustic Recorders (HARPs) have been deployed in the and around the Santa Barbara Channel by Scripps Insitution of Oceanography with support from NOAA Fisheries Acoustics Program. The HARPs have provided valuable data on the spectral and sound level propoerties of individual ships.

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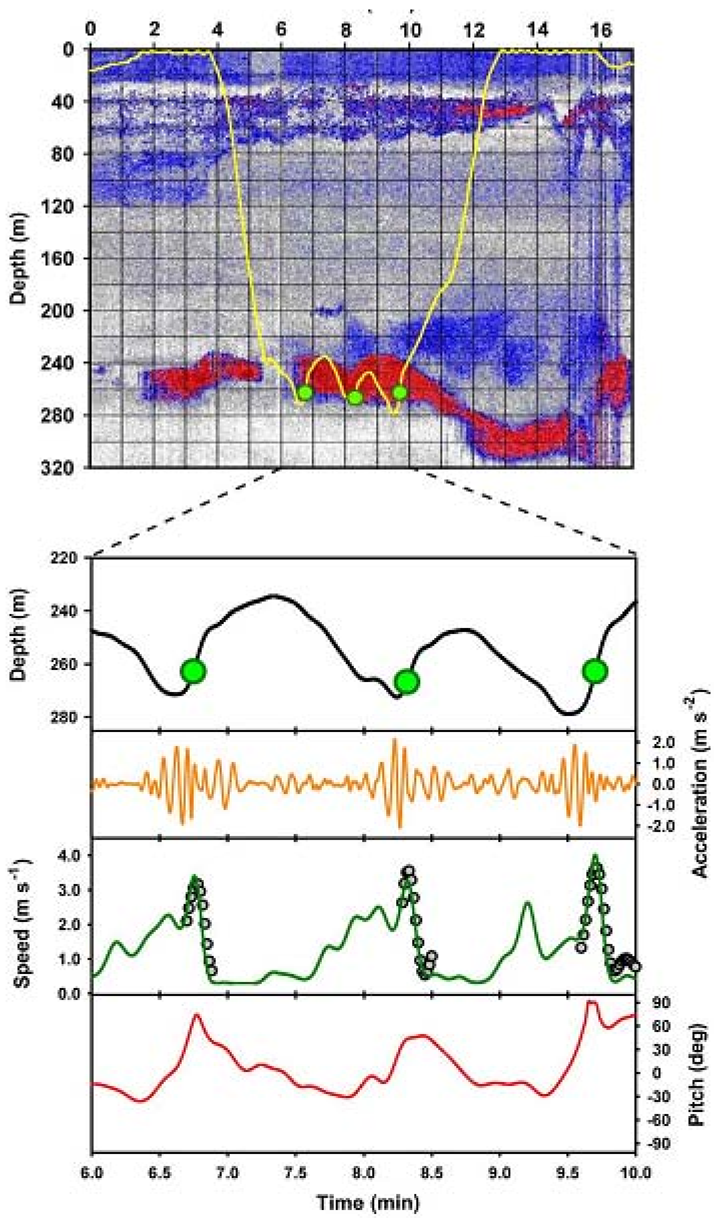

Figure 1: Kinematics of a blue whale foraging dive, showing the periods of low acceleration and flow noise. Green dots represent when received level measurements were calculated. Figure from Goldbogen et al 2010)

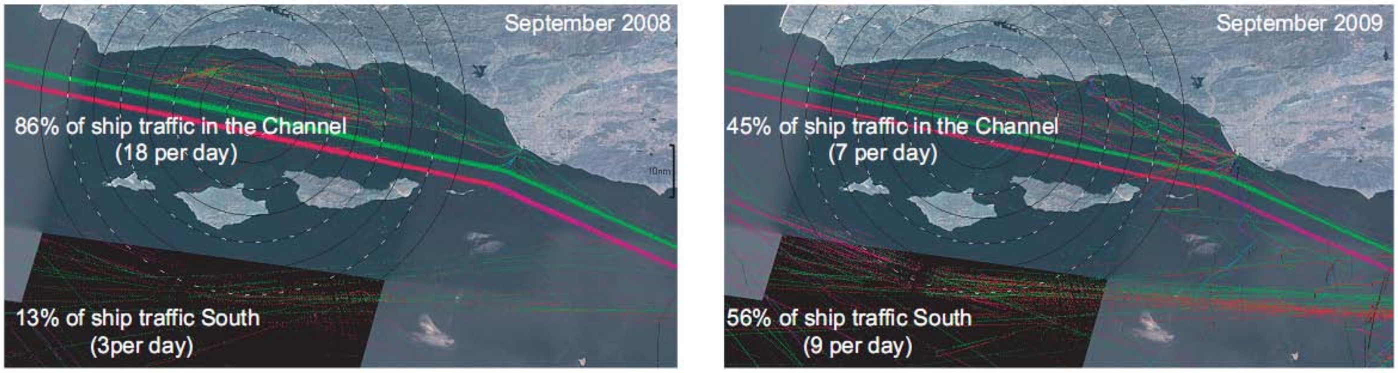

Figure 2. Change in ship traffic in the Santa Barbara Channel after the July 2009 California Air Resources Board Rule

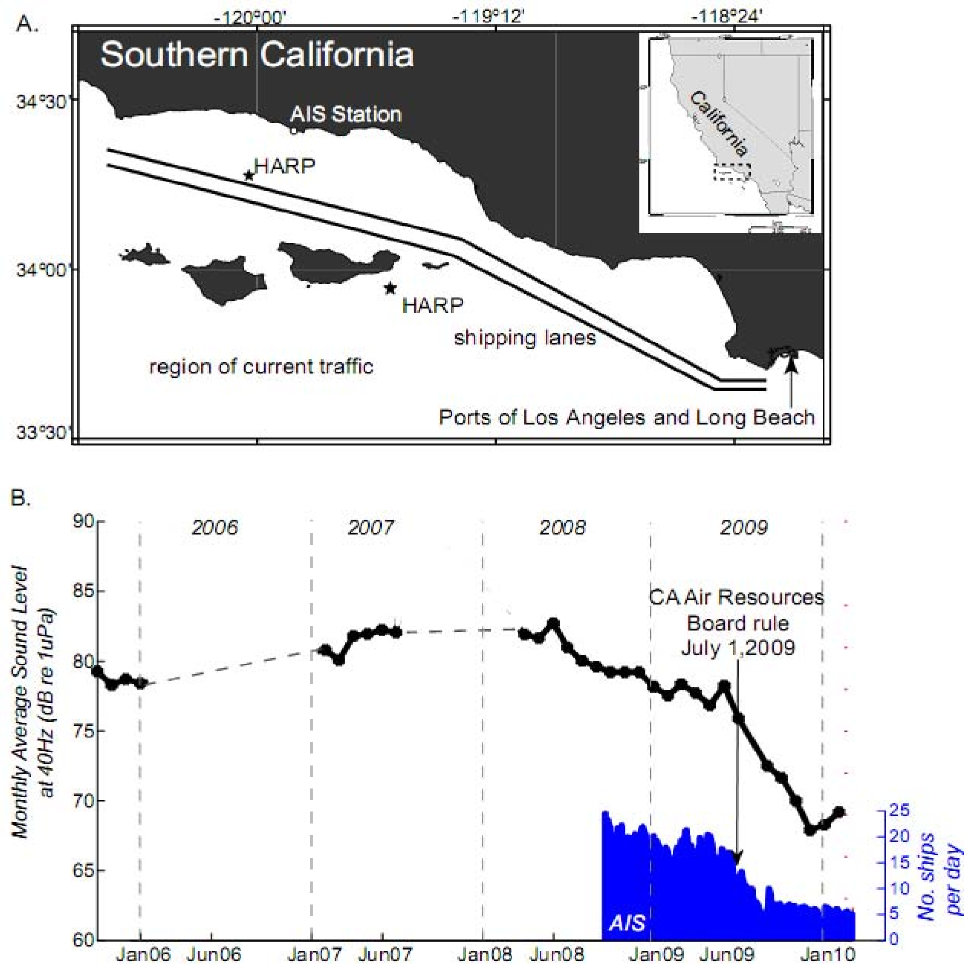

Figure 3. (A) Map of the region, including sites of acoustic recorder (HARP), site of ship transit information (AIS) and the location of the ports of Los Angeles ad Long Beach. (B) Comparison of monthly average sound levels (left axis) and number of loaded outbound ships and average number of ships in the channel from AIS data (right axis).

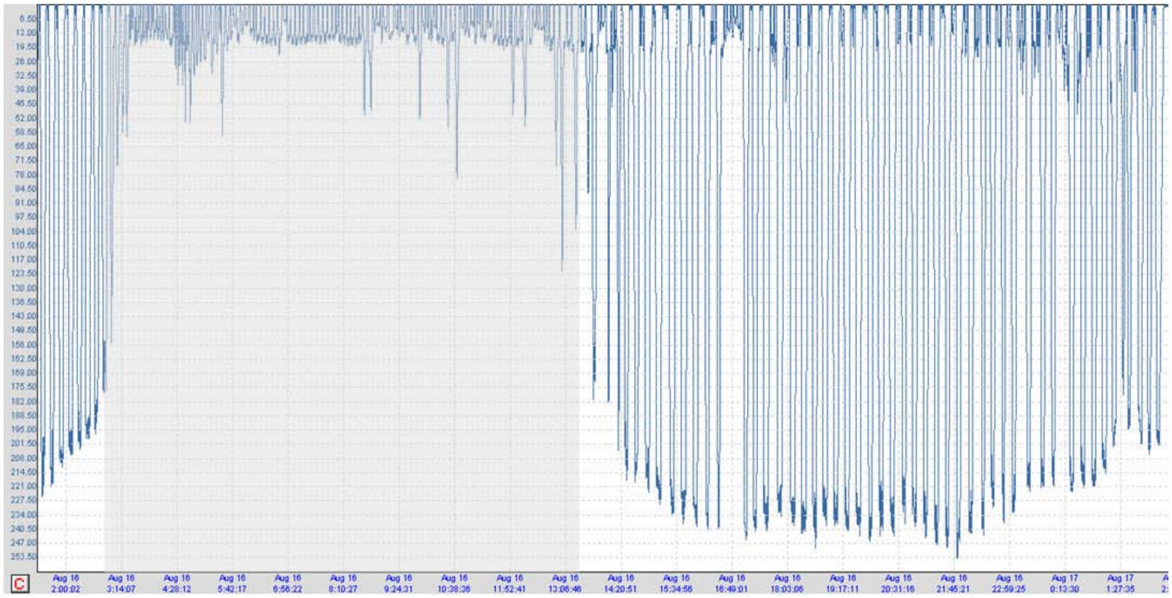

Figure 4 . Dive record for 15-16 August 2008 from blue whale tagged with Mk10 tag and tracked based on Fast-lock GPS. Shaded area shows time between sunset and sunrise, date and time are GMT and depth in meters.

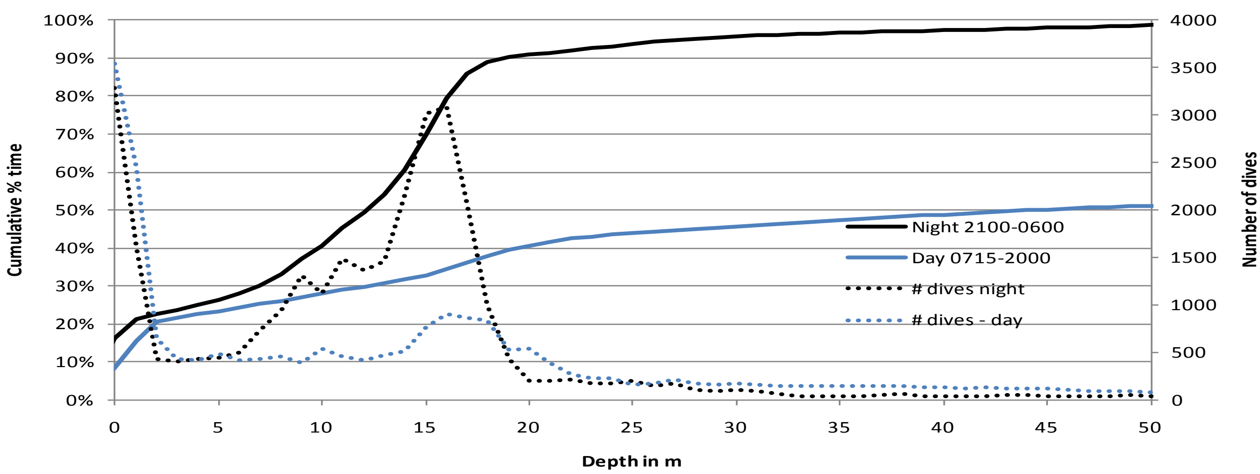

Figure 5. Cumulative proportion of time (solid lines and left axis) blue whales spend at different depths and shallower as well as total number of dives? observations (dotted lines and right axis) by 1 meter intervals for day and night based on 25 hour Mk 10 deployment 15-16 August 2008.

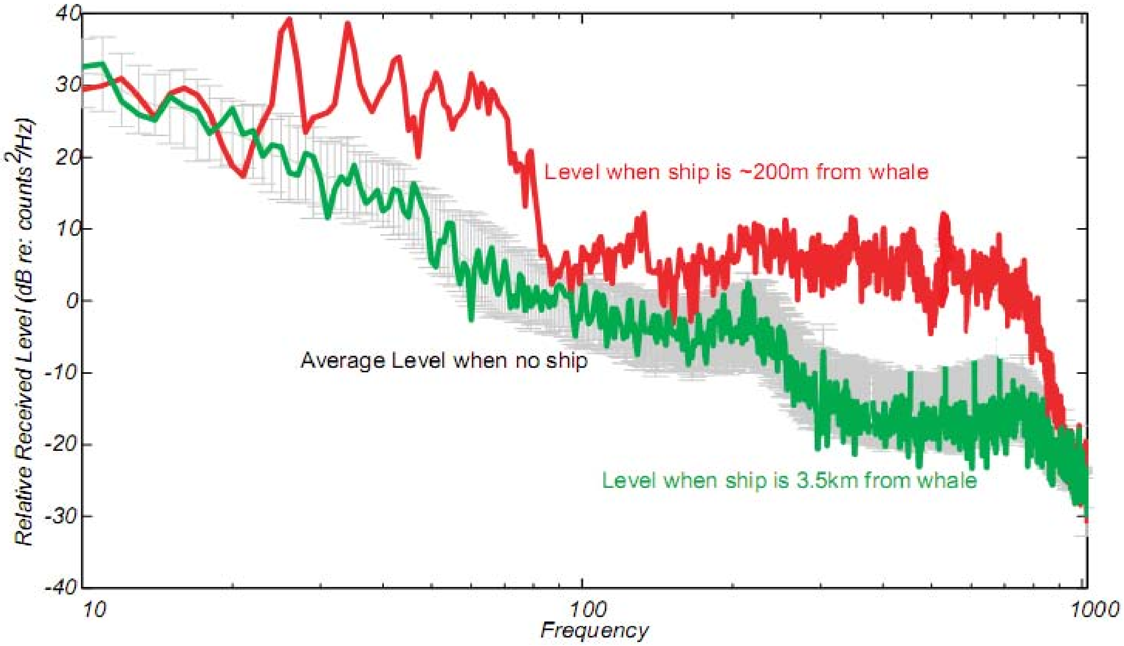

Figure 6. Relative received levels measured on the Bprobe. All measurements were made at the initial deceleration on a deep foraging dive. The gray area represents the mean and standard deviations of all the measured initial decelerations (n=35).

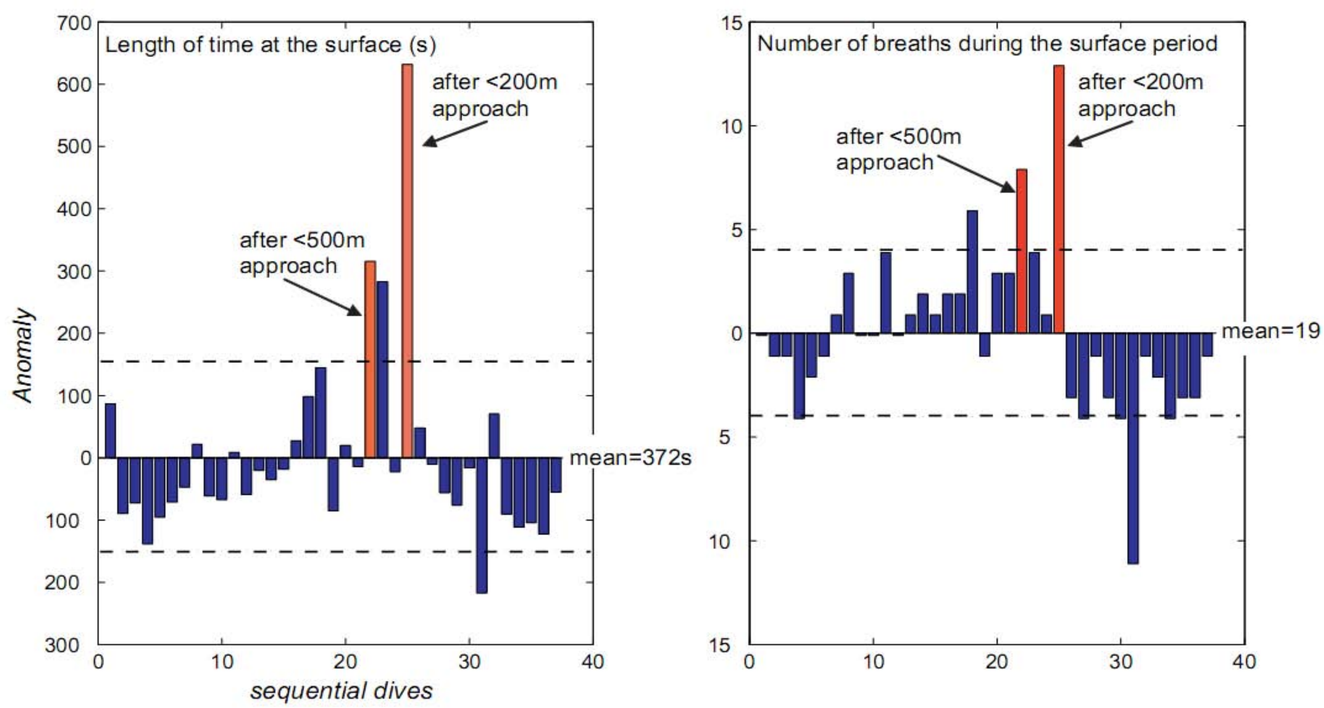

Figure 7: Surface behavior after the close approach of a ship, shown as the difference from the mean of the entire dive sequence (y-axis: 0=mean and dashed lines at one standard deviation). The red bars represent the surface period directly after the close approach of the ship.

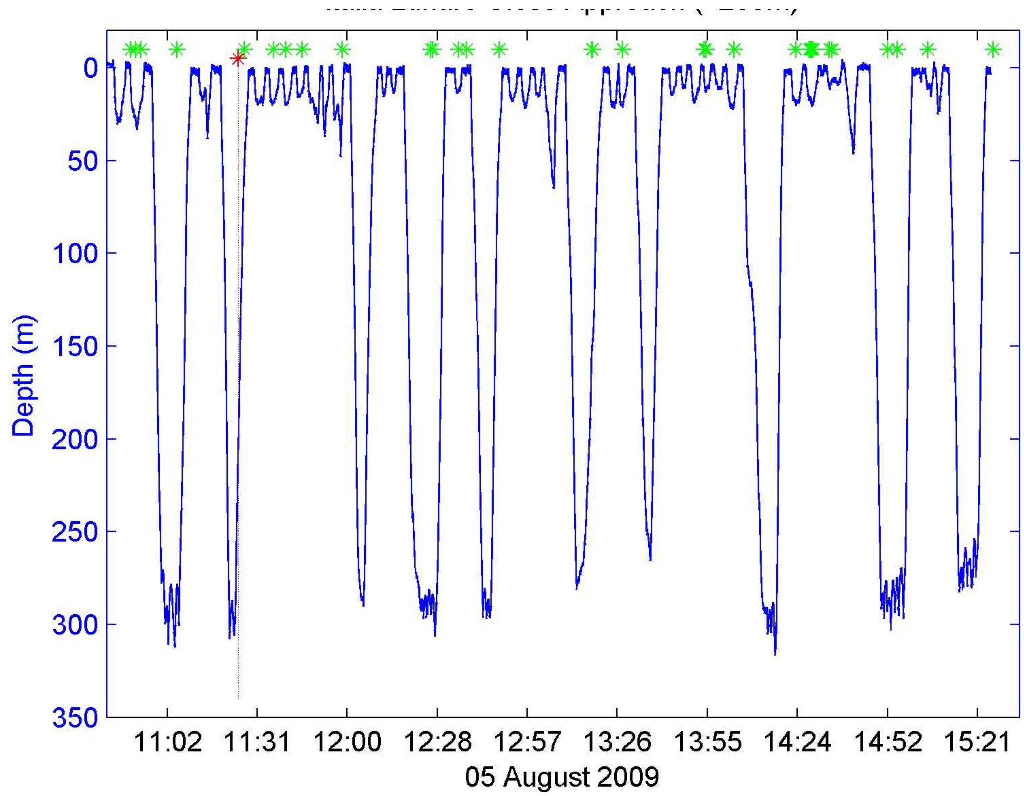

Figure 8: Calling behavior of a blue whale before, after, and during the close approach of a ship. The point of close approach (<200m) with Italia Lunare is represented by the red star. The green stars represent times of calls, including B, A and D calls.